

CLAIMS

What is claimed is:

1. A method of approximating an ion energy distribution function (IEDF) at a substrate surface of a substrate, said substrate being processed in a plasma processing chamber, comprising:

providing a first voltage value, said first voltage value representing a value of a first voltage that represents a DC potential (V_{DC}) at said substrate surface;

providing a peak low frequency RF voltage value ($V_{LFRF(PEAK)}$) during plasma processing, said peak low frequency RF voltage ($V_{LFRF(PEAK)}$) value representing a peak value of a low frequency RF voltage (V_{LFRF}) supplied to said plasma processing chamber;

providing a computing device configured to compute said IEDF from said first voltage value and said peak low frequency RF voltage value ($V_{LFRF(PEAK)}$) in accordance with

$$f(E) \equiv \left(\frac{dV_{LF}}{dt} \right)^{-1}$$

wherein

$$V_{LF}(t) = \left[\left(\frac{V_{LFRF(PEAK)} - V_{dc}}{2} \right)^{1/2} - \left(\frac{V_{LFRF(PEAK)} - V_{dc}}{8} \right)^{1/2} \sin \omega t \right]^2.$$

2. The method of claim 1 wherein said substrate is disposed on a chuck, said chuck being coupled to a bias compensation circuit, a bias compensation voltage obtained from said bias compensation circuit being employed as said first voltage.

3. The method of claim 2 wherein said chuck is also coupled to a V-I probe that is configured to provide said peak low frequency RF voltage value ($V_{LFRF(PEAK)}$).

4. The method of claim 3 wherein said plasma processing chamber is energized with at least one low frequency RF source operatively coupled to said chuck to provide a low-frequency RF signal to said chuck, a frequency of said low-frequency RF signal corresponding to a frequency of said peak low frequency RF voltage ($V_{LFRF(PEAK)}$).

5. The method of claim 4 wherein said plasma processing chamber is further energized with a high-frequency RF source, said high-frequency RF source providing a high frequency RF signal having a frequency higher than said frequency of said low-frequency RF source.
6. The method of claim 5 wherein said high frequency RF source is operatively coupled to provide said high frequency RF signal to said chuck.
7. The method of claim 5 wherein said high frequency RF source is operatively coupled to provide said high frequency RF signal to an electrode disposed above said substrate.
8. The method of claim 1 wherein said plasma processing chamber represents a capacitively-coupled plasma processing chamber.
9. The method of claim 1 wherein said plasma processing chamber is configured to etch said substrate.
10. The method of claim 1 wherein said first voltage is measured using a probe that contacts said substrate surface during said plasma processing.
11. The method of claim 1 wherein said first voltage is approximated using a multivariate plasma modeling approach.
12. The method of claim 1 wherein said substrate is disposed on a chuck during said plasma processing, said peak low frequency RF voltage ($V_{LFRF(PEAK)}$) is measured using a probe coupled to said chuck.
13. A method of controlling plasma processing in a plasma processing chamber, said plasma processing being configured to process a substrate while said substrate is disposed on a chuck of said plasma processing chamber, comprising:
 - providing a first voltage value, said first voltage value representing a value of a first voltage that represents a DC potential (V_{DC}) at said substrate surface during plasma processing;

providing a peak low frequency RF voltage value ($V_{LFRF(PEAK)}$) during plasma processing, said peak low frequency RF voltage ($V_{LFRF(PEAK)}$) value representing a peak value of a low frequency RF voltage (V_{LFRF}) supplied to said chuck;

providing a computing device configured for computing said IEDF from said first voltage value and said peak low frequency RF voltage value ($V_{LFRF(PEAK)}$) in accordance with

$$f(E) \equiv \left(\frac{dV_{LF}}{dt} \right)^{-1}$$

wherein

$$V_{LF}(t) = \left[\left(\frac{V_{LFRF(PEAK)} - V_{dc}}{2} \right)^{1/2} - \left(\frac{V_{LFRF(PEAK)} - V_{dc}}{8} \right)^{1/2} \sin \omega t \right]^2 ; \text{ and}$$

modifying at least one process parameter associated with a process recipe employed during said plasma processing responsive to a value of said IEDF.

14. The method of claim 13 wherein said chuck is coupled to a bias compensation circuit, a bias compensation voltage obtained from said bias compensation circuit being employed as said first voltage.

15. The method of claim 14 wherein said chuck is also coupled to a V-I probe that is configured to measure said peak low frequency RF voltage value ($V_{LFRF(PEAK)}$).

16. The method of claim 15 wherein said plasma processing chamber is energized with at least one low frequency RF source operatively coupled to said chuck to provide a low-frequency RF signal to said chuck, a frequency of said low-frequency RF signal corresponding to a frequency of said low frequency RF voltage (V_{LFRF}).

17. The method of claim 16 wherein said plasma processing chamber is further energized with a high-frequency RF source, said high-frequency RF source providing a high frequency RF signal having a frequency higher than said frequency of said low-frequency RF source.

18. The method of claim 17 wherein said high frequency RF source is operatively coupled to provide said high frequency RF signal to said chuck.

19. The method of claim 17 wherein said high frequency RF source is operatively coupled to provide said high frequency RF signal to an electrode disposed above said substrate.
20. The method of claim 13 wherein said plasma processing chamber represents a capacitively-coupled plasma processing chamber.
21. The method of claim 13 wherein said plasma processing chamber is configured to etch said substrate.
22. The method of claim 13 wherein said providing a first voltage value and said providing said peak low frequency RF voltage value ($V_{\text{LFRF(PEAK)}}$) are performed on a continuous basis.
23. The method of claim 13 wherein said providing a first voltage value and said providing said peak low frequency RF voltage value ($V_{\text{LFRF(PEAK)}}$) are performed on a periodic basis.
24. The method of claim 13 wherein said first voltage is measured using a probe that contacts said substrate surface during said plasma processing.
25. The method of claim 13 wherein said first voltage is approximated using a multivariate plasma modeling approach.
26. The method of claim 13 wherein said peak low frequency RF voltage ($V_{\text{LFRF(PEAK)}}$) is measured using a probe coupled to said chuck.
27. An arrangement for approximating an ion energy distribution function (IEDF) at a substrate surface of a substrate, said substrate being processed in a plasma processing chamber, comprising:
a first circuit for obtaining a first voltage value, said first voltage value representing a value of a first voltage that represents a DC potential (V_{DC}) at said substrate surface;

a second circuit for obtaining a peak low frequency RF voltage value ($V_{LFRF(PEAK)}$) during plasma processing, said peak low frequency RF voltage ($V_{LFRF(PEAK)}$) value representing a peak value of a low frequency RF voltage (V_{LFRF}) supplied to said plasma processing chamber;

a computing device configured to compute said IEDF from said first voltage value and said peak low frequency RF voltage ($V_{LFRF(PEAK)}$) in accordance with

$$f(E) \equiv \left(\frac{dV_{LF}}{dt} \right)^{-1}$$

wherein

$$V_{LF}(t) = \left[\left(\frac{V_{LFRF(PEAK)} - V_{dc}}{2} \right)^{1/2} - \left(\frac{V_{LFRF(PEAK)} - V_{dc}}{8} \right)^{1/2} \sin \omega t \right]^2.$$

28. The arrangement of claim 27 wherein said substrate is disposed on a chuck, said chuck being coupled to a bias compensation circuit, a bias compensation voltage obtained from said bias compensation circuit being employed as said first voltage.

29. The arrangement of claim 28 wherein said chuck is also coupled to a V-I probe that is configured to provide said peak low frequency RF voltage ($V_{LFRF(PEAK)}$).

30. The arrangement of claim 29 wherein said plasma processing chamber is energized with at least one low frequency RF source operatively coupled to said chuck to provide a low-frequency RF signal to said chuck, a frequency of said low-frequency RF signal corresponding to a frequency of said peak low frequency RF voltage ($V_{LFRF(PEAK)}$).

31. The arrangement of claim 30 wherein said plasma processing chamber is further energized with a high-frequency RF source, said high-frequency RF source providing a high frequency RF signal having a frequency higher than said frequency of said low-frequency RF source.

32. The arrangement of claim 31 wherein said high frequency RF source is operatively coupled to provide said high frequency RF signal to said chuck.

33. The arrangement of claim 31 wherein said high frequency RF source is operatively coupled to provide said high frequency RF signal to an electrode disposed above said substrate.
34. The arrangement of claim 27 wherein said plasma processing chamber represents a capacitively-coupled plasma processing chamber.
35. The arrangement of claim 27 wherein said plasma processing chamber is configured to etch said substrate.
36. The arrangement of claim 27 wherein said first voltage is measured using a probe that contacts said substrate surface during said plasma processing.
37. The arrangement of claim 27 wherein said first voltage is approximated using a multivariate plasma modeling approach.
38. The arrangement of claim 27 wherein said substrate is disposed on a chuck during said plasma processing, said peak low frequency RF voltage ($V_{LFRF(PEAK)}$) is measured using a probe coupled to said chuck.
39. The arrangement of claim 27 wherein said peak low frequency RF voltage value ($V_{LFRF(PEAK)}$) is associated with a periodic, non-sinusoidal RF signal.
40. The arrangement of claim 39 wherein said peak low frequency RF voltage value ($V_{LFRF(PEAK)}$) is associated with a pulsed RF signal.
41. The arrangement of claim 39 wherein said peak low frequency RF voltage value ($V_{LFRF(PEAK)}$) is associated with a tailored-waveform RF signal.